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Title: 1L Mark-IV Target Design Review

Author(s): Koehler, Paul E.

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1L Mark-IV Target Design Review

The 1L Target Team

Paul Koehler, Don Brown, Bjorn Clausen, Aaron Couture, Eron Kerstiens, Michael Mocko, Suzanne Nowicki, Joe O'Toole, Fredrik Tovesson, Ray Valicenti, Sven Vogel, Erik Watkins, Steve Wender, and Lukas Zavorka

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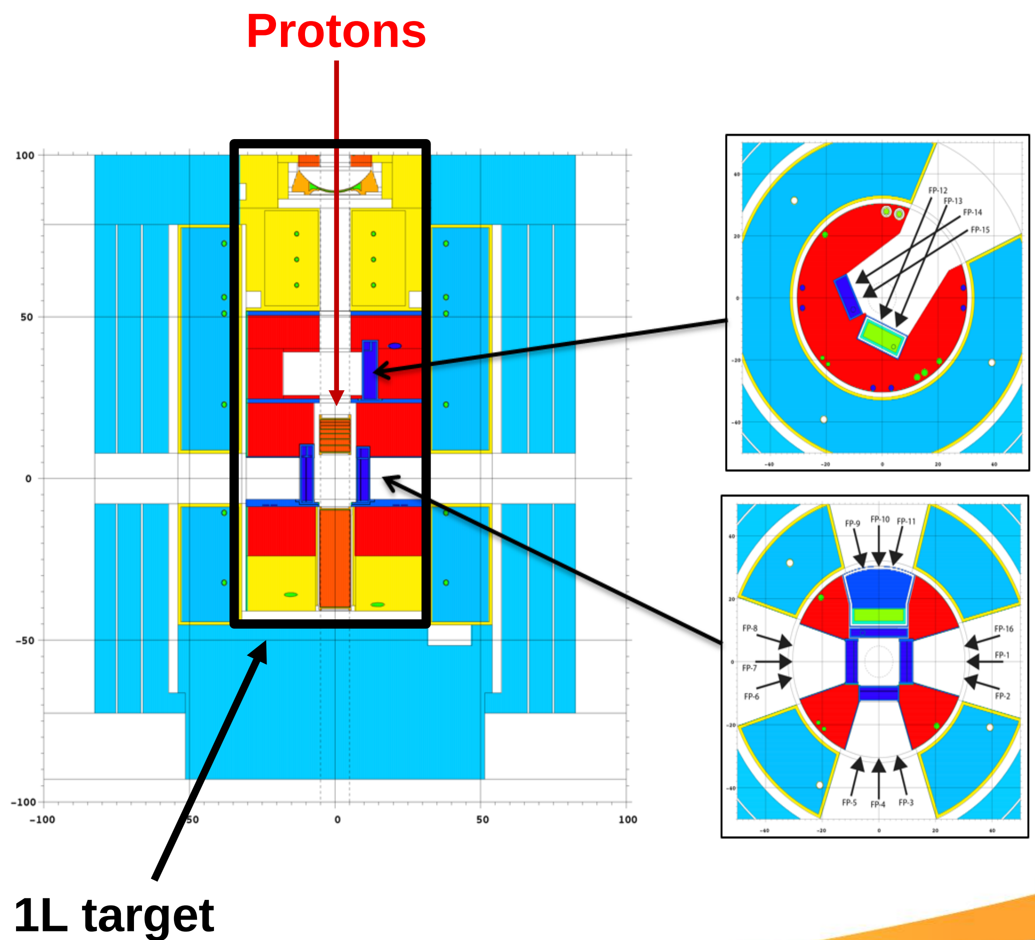
General Design Considerations

- Goals
  Improve performance for nuclear science – higher flux at keV energies and better resolution
  Maintain materials-science performance
  Budget <$10M

- Two-tiered layout of Lujan Center 1L target leads to the obvious decision to optimize one tier for each type of science
  Upper tier for nuclear
  Lower tier for materials



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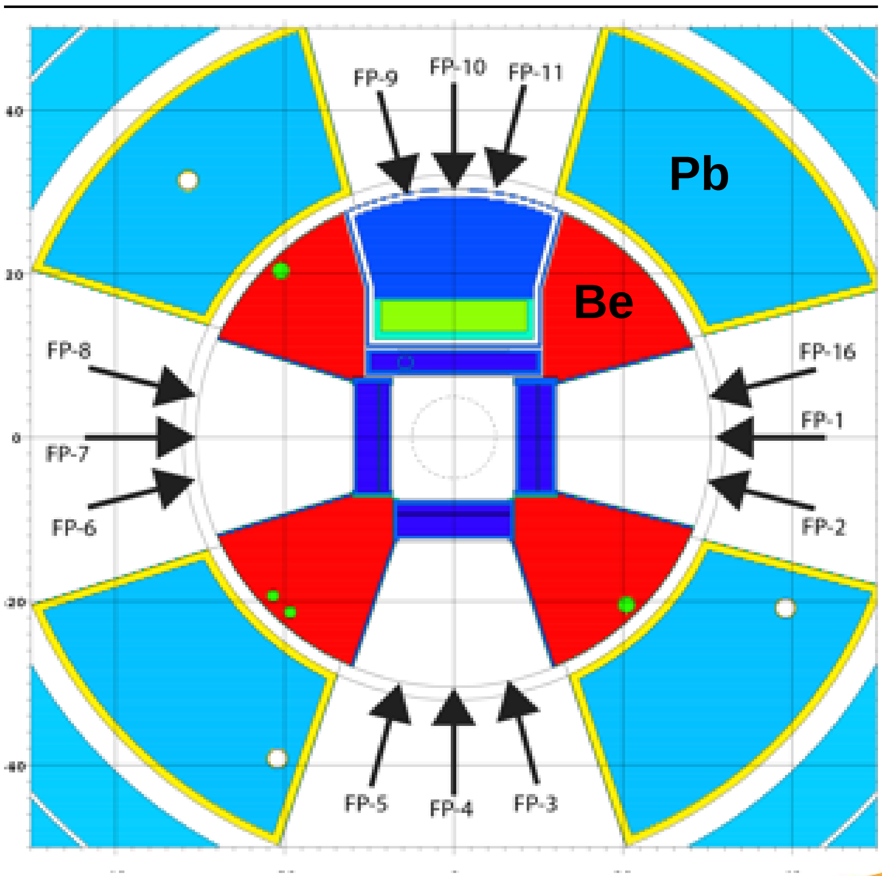
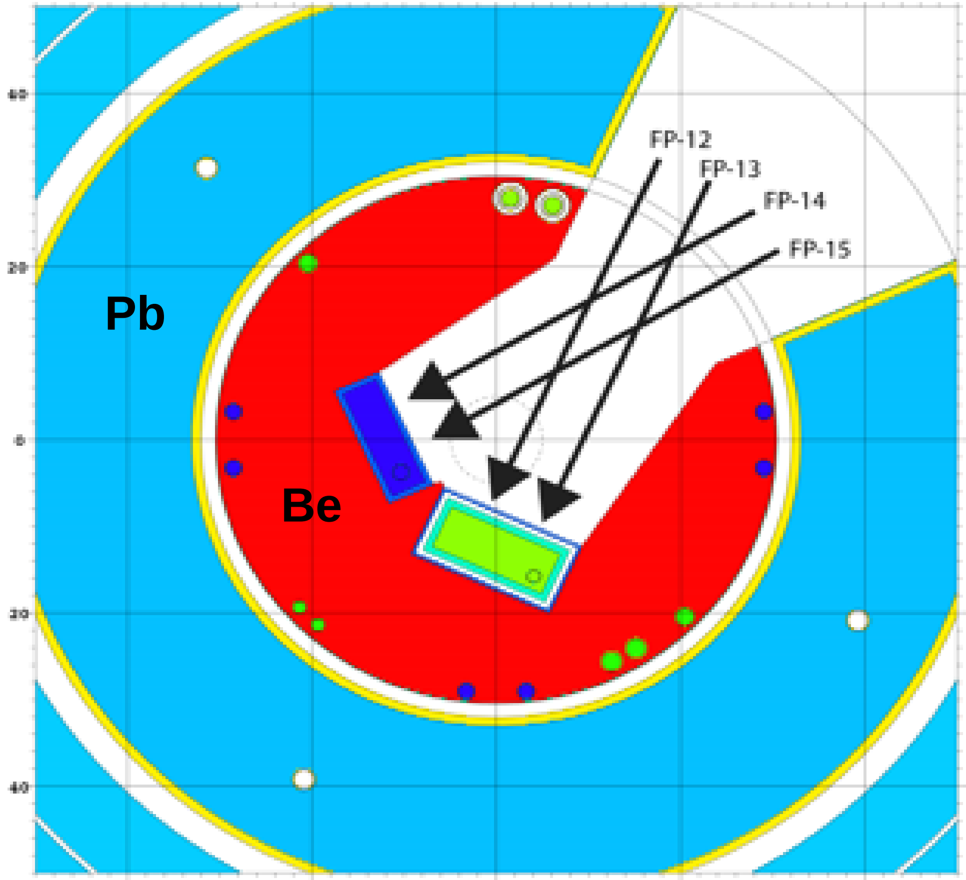
Current (Mark-III) Lower Tier

- Optimized for thermal and cold neutrons
- Flux trap geometry
- Two high-intensity (HI) and one high-resolution (HR) water and one liquid hydrogen (LH) moderators
- Surrounded by Be and Pb reflectors with Cd decoupling layers
- Instruments on flight path (FP) 2 (SMARTS), 4 (HIPPO), 5 (radiography), and 11 (ASTERIX)



Mark-III Upper Tier

- Optimized for cold and thermal neutrons
- Back-scatter geometry
- One water and one LH moderator
- Surrounded by Be and Pb reflectors
- Instruments on FP 12 (general purpose), 13 (DICER, under development), and 14 (DANCE)



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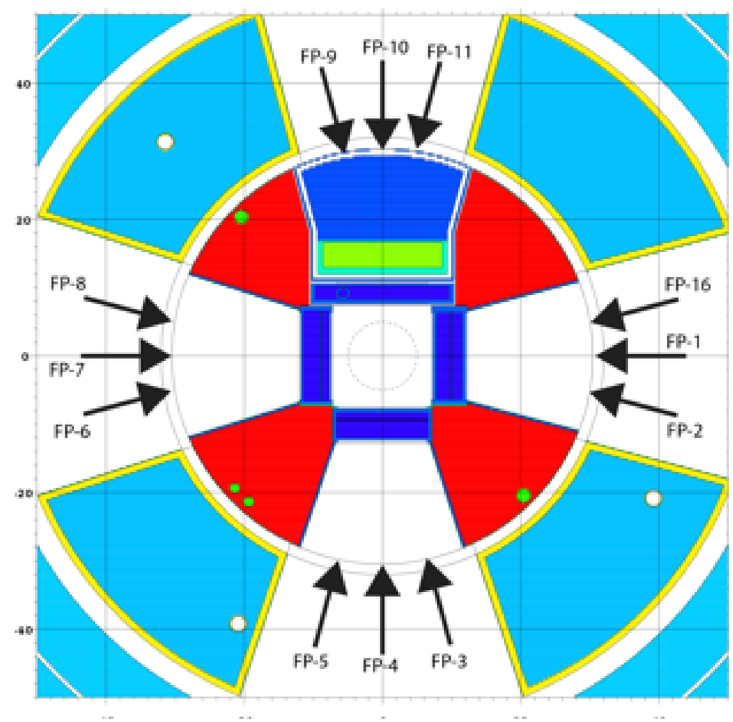
Performance Metrics

- **Average flux, $\phi(E)$**
  Determines sample size and run length
- **Peak flux**
  Ability to use unstable samples
- **Resolution**
  Resolving peaks/dips crucial
  Broadens physics reach
  Improves S/N and reduces systematic uncertainties
- **Background(s)**
  Contributes to statistical precision and run length
- **Repetition rate**
  Time-dependent samples, determines instantaneous data rate
- $FOM = \frac{\phi}{\Delta E^2}$

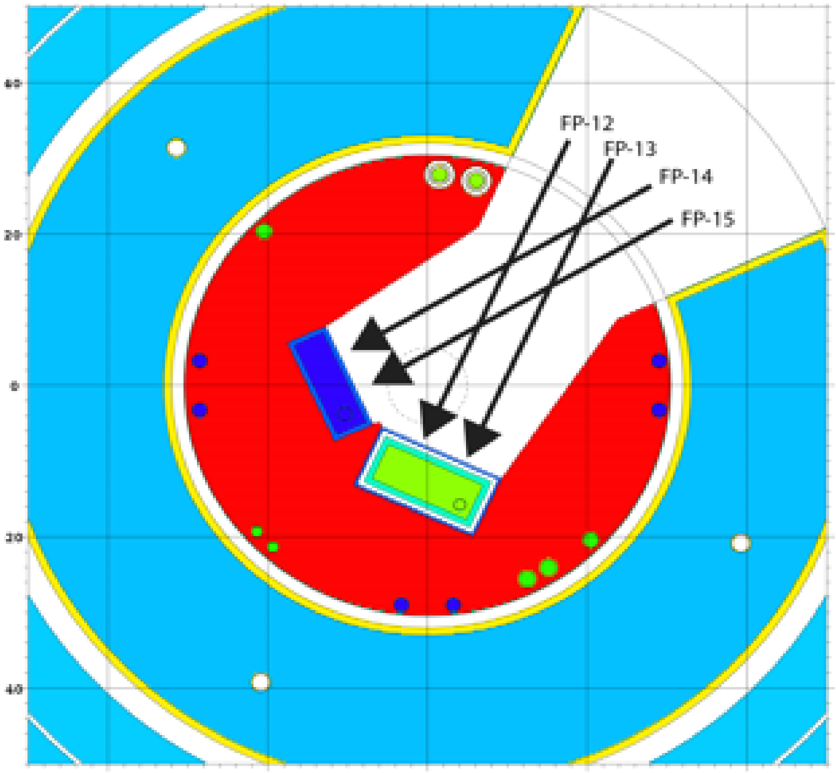
General Improvements for Material Science

- **Mark III already optimized for material science**
  Exotic moderator material beyond scope
  No gain from backscatter geometry
- **Convert HR to HR/HI moderator (SMARTS)**
- **Optimized W sizes and positions**
- **Run at higher repetition rate**
  Improves FP-5, HIPPO, and most SMARTS experiments
  Enables fast-annealing experiments
  Decreases WNR performance
- **Increase average current**
  Used to run at 125 μA/20 Hz



General Improvements for Nuclear Science

- **Remove Be and Pb**
  Improves resolution
  Removing Pb cost prohibitive, but lining with water 80% effective
- **Move W into/near field of view**
  Increases keV flux
  Improves resolution
  Increases prompt γ background
  Decreases lower-tier flux
- **Limit target/moderator thickness**
  Improves resolution
  Little impact on (useful) flux
- **Realign FP's for centered FOV**
  Increases flux and improves resolution



Improving FOM for Nuclear Science

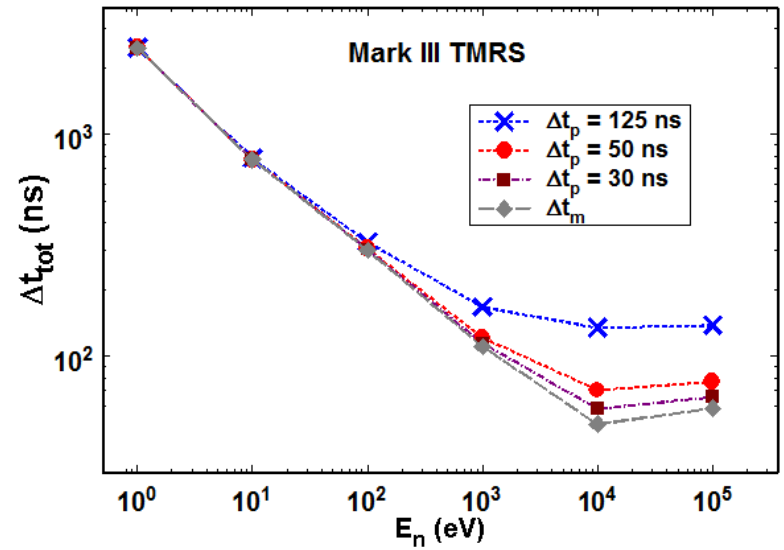
- **Mark-III limited by TMRS resolution**

$$\Delta t_{tot} = \sqrt{\Delta t_m^2 + \Delta t_p^2}$$

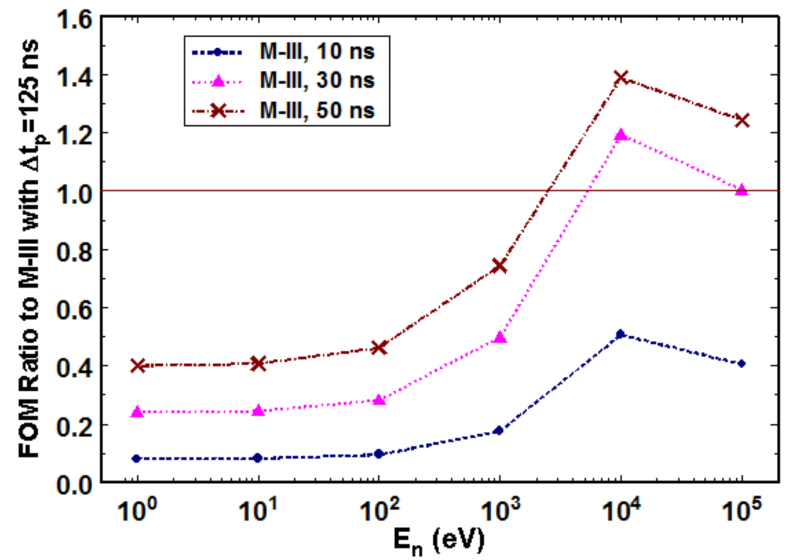
$$\phi \propto \Delta t_p$$

$$FOM = \frac{\phi}{\Delta t_{tot}^2}$$

$$FOM \propto \frac{\Delta t_p}{\Delta t_p^2 + \Delta t_m^2}$$



- **With Mark-III, loss in flux due to decreasing proton pulse width only marginally offset by improved resolution**



General Design Considerations Summary

- **Goals: improve performance for nuclear science and maintain performance for materials science**
- **Optimize one tier for materials science and one for nuclear science**
- **Mark-III TMRS already optimized for cold and thermal neutrons**
  Limited improvements at these energies possible within budget scope
- **Mark-III TMRS far from optimal for nuclear science**
  Remove reflectors
  Move W into or closer to FOV
  Reduce target thickness
  Realign FP's
- **Operations changes would benefit almost all Lujan science**
  30 Hz
  Higher protons/pulse

Design Optimization Studies

Michael Mocko and Lukas Zavorka

Expected Mark-IV Performance: Material Science

- **Current operating conditions (20 Hz, 100 μA)**

  72 (disk) – 74% (rod) of Mark-III flux (FP-5, HIPPO, and ASTERIX),
  76 (disk, HR) – 116% (rod, HI) for SMARTS

- **30 Hz, 150 μA operation**

  108 – 114% of Mark-III flux for FP-5, HIPPO, and ASTERIX,
  114 (disk, HR) – 170% (rod, HI) for SMARTS
  Enables new fast-annealing experiments
  Effective chopper systems needed for ASTERIX and SMARTS
  10% decrease in WNR flux

- **125 μA, 20 Hz operation**

  90 (disk) to 95% (rod) of Mark-III flux (FP-5, HIPPO, and ASTERIX),
  95 (disk, HR) – 145% (rod, HI) for SMARTS

Expected Mark-IV Performance: Nuclear Science (Disk)

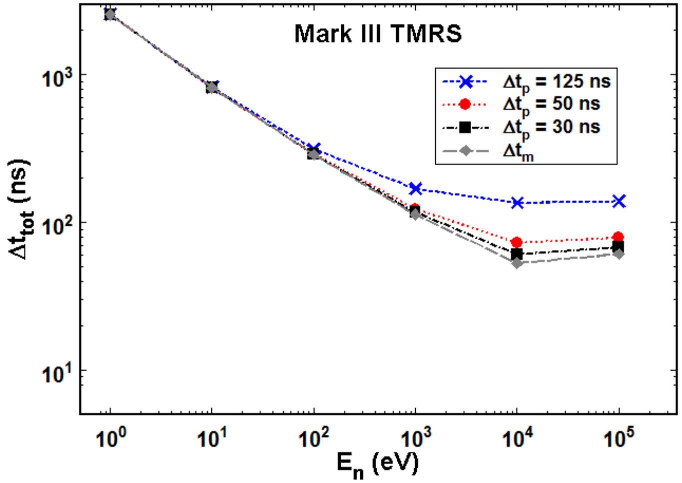
- **Current operating conditions (20 Hz, 100 μA)**
  5.5 (12) times higher flux than Mark-III at 10 (100) keV
  Δt_{tot} reduced to 93% (90%) of Mark-III at 10 (100) keV
  FOM 6.4 (15) times higher than Mark-III at 10 (100) keV
- **30 Hz, 150 μA operation**
  8.2 (18) times higher flux than Mark-III at 10 (100) keV
  Δt_{tot} reduced to 93% (90%) of Mark-III at 10 (100) keV
  FOM 9.6 (23) times higher than Mark-III at 10 (100) keV
- **30 Hz, 36 μA operation (Δt_p = 30 ns)**
  2.0 (4.4) times higher flux than Mark-III at 10 (100) keV
  Δt_{tot} reduced to 25% (22%) of Mark-III at 10 (100) keV
  FOM 32 (91) times higher than Mark-III at 10 (100) keV

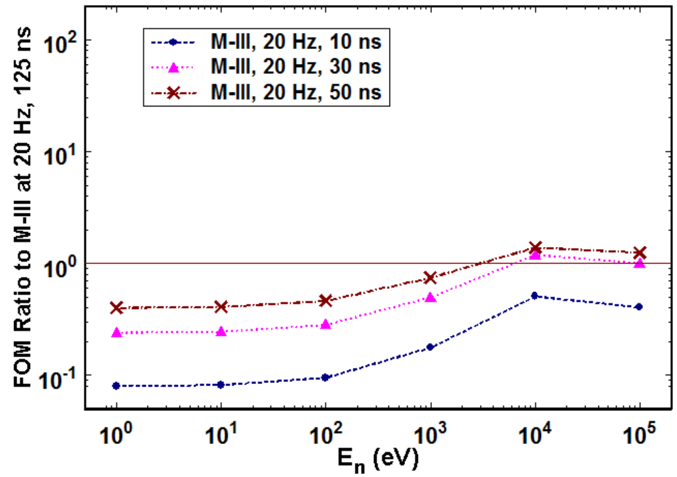
Mark IV Enables Much Wider Range of Nuclear-Science FOM Gains than Mark III

Δt_{tot}

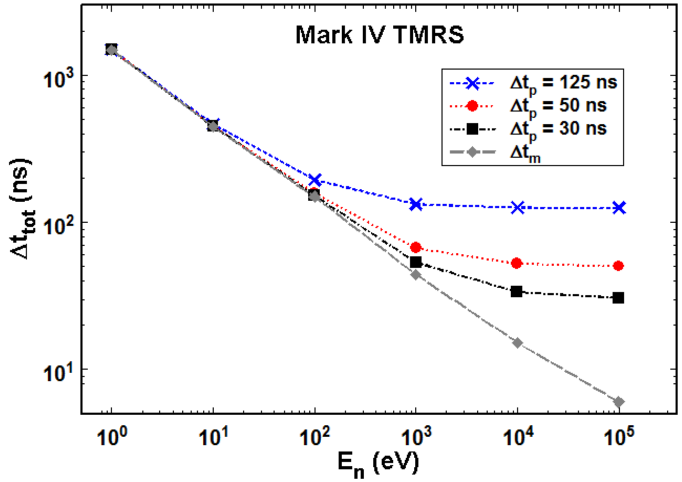
FOM

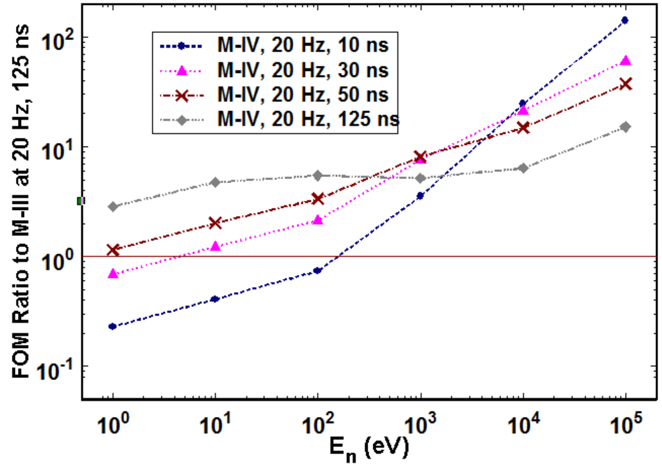
Mark III





Mark IV





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Mark-IV Performance Summary

- **Materials science performance maintained close to Mark III or better**
  72% – 116% of Mark III at standard operation (20 Hz, 125 ns)
- **Nuclear science FOM ≈ 10 times better under standard operation**
- **More flexible than Mark III**

Row	Design	PSR parameters			DANCE ratios (10 keV/100 keV)			SMARTS ratios	
		ν_p (Hz)	I_p (μA)	Δt (ns)	ϕ	Δt_{tot}	FOM	ϕ_{HR}	ϕ_{HI}
1	III	20	100	125	1/1	1/1	1/1	1	-
2	III	20	24	30	0.24/0.24	0.45/0.49	1.2/1.0	0.24	-
3	III	30	36	30	0.36/0.36	0.45/0.49	1.8/1.5	0.36	-
4	IV	20	100	125	5.5/12	0.93/0.90	6.4/15	0.76	1.13
5	IV	30	150	125	8.2/18.4	0.93/0.90	9.6/23	1.14	1.7
6	IV	20	24	30	1.3/2.9	0.25/0.22	22/61	0.18	0.27
7	IV	30	36	30	2.0/4.4	0.25/0.22	32/91	0.27	0.41
8	IV	30	12	10	0.66/1.5	0.13/0.084	37/209	0.1	0.14

Rod or Disk?
Center or Real FOV?

- **Disk vs. Rod: Is a 2x larger FOM worth 1.5 – 2x more prompt γ bkg?**
- **Center vs. Real: Is a 2x larger FOM worth 4.5 – 6x more prompt γ bkg?**
- **Disk with center FOV will have the most uniform beam**
- **Prompt γ bkg less than at n_TOF**
- **Delayed γ bkg about the same as Mark III (and less than at n_TOF)**

Design	FOV	FOM ratio	γ-ray bkg ratio (prompt : delayed)	M4/M3 lower-tier flux (%)
Disk	Center	4	9 : 2	72
	Real	2	2 : 2	72
Rod	Center	2	6 : 2	74
	Real	1	1 : 1	74

Project Cost and Schedule

Joe O'Toole